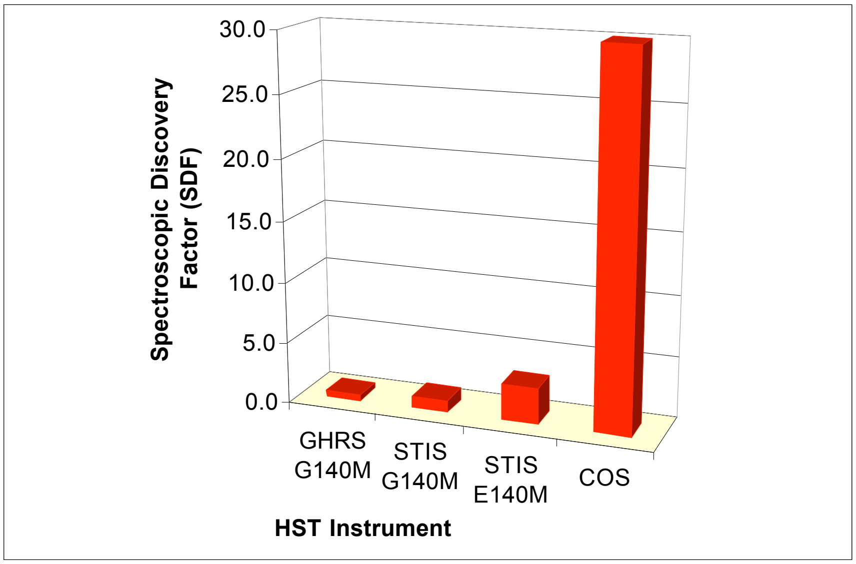
Astronomical Instrumentation for Servicing Mission V

An additional servicing mission for the Hubble Space Telescope (HST) is being considered, extending the mission life and possibly expanding the capability through the installation of new instrumentation. The scientific rationale for these capabilities is well supported. Besides specific scientific questions that could be addressed by new instrumentation, broadly capable instrumentation would undoubtedly be employed by numerous guest investigators to address issues which are not yet appreciated. However these benefits must be weighed against the lost opportunities that the funds for an SM5 would necessitate, as well as the practical realities of selecting, building and installing new instrumentation with enough time left in the mission life to justify their expense. I will focus on possible new instrumentation and a new paradigm for instrument development that I feel will allow the successful incorporation of new capabilities in a future SM5.

Hubble's Science Return

Even given the great cost of developing and maintaining HST, its scientific return is aptly demonstrated by the significant and continuing scientific publications and references in the popular press. I refer the reader to the summation by Steven Beckwith, available at this web site, which quantifies these performance metrics and makes clear the continuing scientific productivity of the Hubble. As an addition to that report, I present a "discovery factor" for spectroscopic missions during the history of HST. This Spectroscopic Discovery Factor (SDF) is instrumental effective area times simultaneous wavelength coverage, which maps directly to information content, similar to the familiar Imaging Discovery Factor of Quantum Efficiency times Field of View. For comparison purposes, "M" modes have been chosen and the performance evaluated at 1300 Å. The data are normalized for STIS G140M = 1 (current HST performance).



An SM5 that only extended the mission life of the observatory would still of great value, as WFC3 and COS greatly extend the discovery space of HST and promise an increasing yield of scientific results. Unfortunately this state may only be maintained for 3-5 years, depending upon the actual SM4 launch date and the date of decommissioning. New instruments hold out the promise of even greater scientific return through the application of the latest technologies and instrumental designs. However, the cost of an additional servicing mission, as well as the programmatic constraints on new instrumentation need to be justified and validated prior to any decision on an SM5 instrument AO. It is to these issues that I will focus my comments.

Potential Instrumentation

Two candidate instruments have been extensively discussed: a wide field imager and a coronagraph. The wide field imager is discussed in at least one other presentation, and the coronagraph may be as well. I will not discuss the merits of these two concepts in this presentation. Instead, I would like to encourage the community to consider an open Announcement of Opportunity for new instrumentation, and let a scientific review panel select the most appropriate instrumentation for SM5 from all possible candidate instruments. I briefly present two alternate instrument concepts to demonstrate the potential variety that such an AO might solicit.

A: High Throughput Ultraviolet Spectroscopy in the Near Ultraviolet (1800-3000Å)

The Cosmic Origins Spectrograph (COS) provided a more than 10-fold increase in observable faint quasars for studies of the Lyα forest in the spectral range 1150-1775Å. The instrument also includes observing capability in the NUV (1750-3200Å) but this performance is complimentary, being only marginally more sensitive than STIS in this wavelength region, and does not represent a breakthrough in observing capability in the bandpass. However, λ=1775 represents Lyα at a redshift z = 0.46. Probing the structure of the baryonic filaments at higher redshift requires moving into the NUV.

One of the fundamental reasons for probing the IGM structure is to determine the history of the evolution of structure. A single snapshot in cosmological history, while valuable, does not complete the picture. The IGM-galaxy connection, probed by QSO lines of sight that pass near distant galaxies, requires fortunate coincidences of line of sight. The likelihood of finding such suitable alignments greatly increases with instrument sensitivity. It may be that feedback mechanisms are crucial to our understanding of galaxy formation and IGM enrichment, and that the feedback efficiency evolves with look back time. If so, a more complete sampling of galaxies out to z ~ 1.5 is essential to reconcile models of structure formation with our present values of the fundamental cosmological parameters.

The break between FUV and NUV is a technological, not scientific one. It is driven by photocathode and solid state quantum response. The key technological factor in the COS SDF improvement in the FUV is the employment of a large format detector, allowing significant wavelength coverage with a single dispersive element. This can be accomplished in the NUV with rectangular CCD's or large format MCP detectors. An optical design around such elements could lead to comparable improvements (factors of 10) in the SDF for an NUV spectrograph.

B: Low Surface Brightness Camera

One of the difficult problems in astronomy today is accounting for the baryons at various redshift epochs. Numerical structure simulations often predict the presence of numerous "satellite" structures associated with galaxies that are not observed. One explanation is that the baryons reside in structures with very low surface brightness and remain undetected. Designing a camera to search for such objects efficiently is straightforward; however, the optimization of such a system is quite different than a design for a camera that is optimized for detecting point sources. Two basic elements would exist in such a design: 1) the sky coverage per pixel would be large, rather than small, to maximize the diffuse signal. For point source detection, pixel scale should be small, to reduce sky background while point source flux remains constant. 2) Operate in a wavelength regime where the sky brightness is at a minimum. The darkest skies are available in the near ultraviolet, and are accessible only from space. HST is ideally (and currently, uniquely) suited to support such a scientific program. A serendipitous camera could be designed, optimized for detecting low surface brightness objects, which would observe whatever field was selected by other HST instruments. No new technologies are required for its development.

Programmatic Considerations

Two arguments are frequently put forward which challenge the wisdom of developing instruments for an SM5. The first is the cost involved. If the cost of the shuttle flight and servicing mission staff are included in the overall cost, the total cost is large. The actual cost of the instrument development is not the dominant cost of the servicing mission. However, if an SM5 is required for de-orbit or maintenance reasons, the additional cost of including new instruments is comparable to the cost of a MIDEX. The total cost of an SM5 is more comparable to the cost of three MIDEX missions. If the model for financing an SM5 is constrained to requiring such trade-offs, reducing other space science missions in exchange for a currently unfunded SM5, the community must seriously consider which path results in the maximum science return. However, if the cost of the mission is viewed from a total government cost perspective (considering that the shuttle program will go forward in any case, and that the servicing mission staff will continue to be employed), rather than an OSS/Origins perspective, the additional cost of supporting SM5 is more easily justified. I realize that a change from our current zero-sum assumptions probably will only be possible with the concurrence of Congress.

The second argument is schedule, regardless of cost. It is true that the normal time from instrument approval to installation is about 6 years. The argument is that even if the selection of SM5 instruments were initiated immediately, their installation would be so late in the Hubble lifetime that their science return would be marginalized. The solution to this problem is to accelerate instrument development so that installation in 2007 - 2008 would be possible. Having experienced the process first-hand, I can state with confidence that this can be done if schedule, rather than performance, becomes the driving factor in development decisions. This is not meant as a criticism of the current instrument development strategies. HST is the flagship of astronomy, and achieving the best possible instruments is appropriate; this approach has given us the magnificent observatory that we have today, and at least for SM4, is not driving the installation date. COS installation is driven by the scheduling of SM4, and not the instrument development schedule. However, SM5 may have to be developed under a different paradigm. Instruments selected must require no technological development, and have significant performance margin for their science objectives. NASA and the instrument PI must be prepared to sacrifice potential performance for schedule if specifications are being met. A proper selection of SM5 instrumentation, coupled with a top-down philosophy of schedule first, can provide first-rate new instrumentation within a time frame needed for a worthwhile SM5.

Conclusions

If we confine ourselves to past models of cost-justification, development time-scales, and scientific trade-offs, it is difficult to imagine a scenario in which an instrumented SM5 can be justified on its net scientific return or feasibility. Yet I think that many would agree with me that its is just as clear that a continuing, increasingly capable HST is in the interest of the astronomical community, NASA, and the nation. None of these entities is truly prepared for the elimination of the scientific data, public awareness, and positive public support that HST generates. Our task is to find a way to make SM5 a reality within a fiscally responsible, programmatically feasible, and scientifically justifiable approach. A combination of creative design and responsible implementation can be found to meet all of these goals.